Technews

National Dairy Development Board

For Efficient Dairy Plant Operation

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ENERGY MANAGEMENT IN MILK POWDER PLANTS

This bulletin includes technical information based on latest development on products, systems, techniques etc. reported in journals, companies' leaflets and books and based on studies and experience. The technical information on different issues is on different areas of plant operation. It is hoped that the information contained herein will be useful to readers.

The theme of information in this issue is **Energy Management in Milk Powder Plants**. It may be understood that the information given here is by no means complete.

In this issue:

1. INTRODUCTION

Under the liberalized market regime following the implementation of World Trade Organization (WTO) Agreements, there is limited restriction on import of dairy products. Therefore, Indian dairy products have to compete not only with the major global dairy products trading countries in the international market, but with the imported products in the domestic market as well. And the competition would get tougher in coming years.

It is, therefore, imperative that the Indian dairy industry operate most competitively with respect to both the elements of competitiveness – price and quality – to ensure survival. Efficient operation of a dairy plant is not a choice, it is a necessity now.

One of the major aspects of efficient plant operation is heat energy management. Among dairy plants, milk powder plants are the most energy consuming ones. These are also the plants that are operated generally with very low thermal efficiencies and have great scope for heat economization.

For example, studies have shown that the heat lost through the spray dryer exhaust air alone ranges from around 28,000 to 48,000 kcal per 100 kg milk powder produced. Thus, a plant producing 50 tonnes of powder a day loses around 1.5 crore rupees every year through heat in the dryer exhaust air alone. By employing suitable heat recovery systems, at least 50% of it can be saved. These measures would then make the dairy plant price competitive in the market – both domestic and global.

India produces about 3.5 lakh tonnes of whole milk powder and skimmed milk powder annually. Efficient operation of powder plant would make the dairy industry most competitive and viable.

For instance, savings through economization of dryer exhaust air heat alone would be Rs.14 crore annually !

This issue of Technews outlines some measures for heat economization in powder plant.

2. OPERATION PARAMETERS

Milk is concentrated usually to 45-50% concentration in a multiple-effect evaporator usually employing thermal vapour compressor, before it is fed to the spray dryer where it is dried to 3-4% moisture content. Thus 85-95% of the total water evaporation is effected in the evaporating plant and 5-15% in the spray drying plant.

For quality reasons milk should be evaporated at low temperature, at not more than 70-73^{o}C, i.e., under vacuum. At the same time, considering the practical difficulties in maintaining high vacuum, the last effect can have evaporation temperature of around 43-45^{o}C. Thus, the maximum temperature range available is 73-43^{o}C, that is 30^{o}C within which the number of effects are required to operate.

The temperature of the steam (heating medium) must not exceed the boiling temperature of the first calandria by 5-15^{o}C. Hence the heating medium to the first effect should be at 75 to 85^{o}C. This is achieved by thermo-compressing the vapour from the first calandria by the steam at 10-15 kg per sq cm pressure. Typical operating conditions in multiple effect evaporators are provided in Table 1.

Table 1: Evaporating temperatures in multiple-effect evaporator

Calandria	Type of plant									
	3-effect		4-effect		5-effect		6-effect		7-effect	
	Temp°C	Vacuum Cm Hg	Temp°C	Vacuum Cm Hg	Temp°C	Vacuum Cm Hg	Temp°C	Vacuum Cm Hg	Temp°C	Vacuum Cm Hg
1st effect	65	57	68	54	68	54	69	53	70	52
2nd effect	58	62	63	58	63	58	65	57	67	55
3rd effect	48	67	56	63	57	62	61	60	64	58
4th effect			48	67	53	65	57	62	60	61
5th effect					46	68	52	65	55	64
6th effect							45	69	50	66
7th effect									45	69

The vapour from the last effect is condensed in a condenser usually by water at around 30°C. Steam consumption in multiple-effect evaporator using thermocompressor, excluding the saving made by re-using condensate, is provided in Table 2.

Table 2: Steam consumption in multiple-effect evaporator

Type of plant	kg steam / kg water evaporated
3-effect	0.24
4-effect	0.18
5-effect	0.14
6-effect	0.12
7-effect	0.10

The dryer feed is usually preheated to 70-80°C to facilitate efficient atomization of concentrated feed as well as to improve heat economy.

Two-stage spray drying plants are common now, although conventional one-stage spray dryers also are in use. Typical operating conditions in these dryers are given in Table 3.

Table 3: Typical operating parameters of one-stage and 2-stage spray drying plants

Parameter	**One-stage plant**	**2-stage plant**
Spray dryer		
Drying temperature °C	180-200	220-230
Exhaust air temperature °C	85-95	70-80
Fluid bed dryer		
Drying air temperature °C		80-120
Exhaust air temperature °C		60-70

Generally, the energy consumption in spray drying plants is approximately as follows:

Single-stage: 1200 kcal per kg water evaporated
Two-stage : 980 kcal per kg water evaporated

In a typical case where milk of 14% total solids is concentrated in a 4-effect evaporator to 50% solids, and then dried to 3% moisture in a single stage spray dryer, the heat required would be around 1877 kcal per kg powder produced. If the concentrated milk is dried in a 2-stage dryer, first to 7% moisture content in spray dryer and then to 3% moisture content in a fluidized bed dryer, the heat required would be around 1670 kcal per kg of powder. This is over 11% saving.

Proper operation and maintenance of powder plant are necessary to achieve the necessary energy efficiency, but are sadly often neglected. In evaporator, production rates are usually maintained by increasing the steam rates and pressure to overcome fouling or other problems at the expense of additional operating costs, which are mainly due to increased energy use. The major sources of energy losses due to operating factors are outlined below.

Venting rates. Noncondensibles enter the evaporator from inerts in the feed, and air leaks through piping networks. In multiple-effect units, the noncondensibles from earlier effects will enter the steam chest of the next effect. If the venting of the steam chest is inadequate, the noncondensibles accumulate and cause heat-transfer rates to drop. Additional steam at higher pressure is then required to overcome the loss of heat transfer and pressure. The concentration of air necessary to reduce the overall heat-transfer rate can be quite low, less than 2%.

If the venting rate in the steam chest is increased to take care of higher amount of air, thermal efficiency further decreases, as additional steam, commingled with air, is lost to the vents.

It is, therefore, important to prevent any air leak in the system and to optimize the venting to the requirement.

In order to reduce the overall steam losses and to control the venting at desirable level, series staging of the vent, from one effect to the next, can be installed. In this manner the air can be finally vented off the last effect, where the greatest amount of air is present and control is limited to one location.

Vacuum system performance. The vacuum system is important to the thermal efficiency of the operation and is itself an energy user. The vacuum generated by system can be affected by poor condensing rate in the barometric condenser or surface condenser and by the amount of air leakage. For systems using steam ejectors, the performance is also affected by the steam quality, which should be above 98%, condition of the nozzles, and condenser flooding.

If the vacuum is reduced, the loss of ΔT is made up by raising the steam pressure, and the amount of steam required to maintain capacity is increased. For example, consider a triple-effect evaporator with the pressure in the last effect as 63 cm Hg vacuum. For a combination of reasons, a 10% loss in vacuum (i.e. 56.7 cm Hg vacuum) would increase the steam rate by 5%. Maintenance of vacuum is therefore very important.

Water leakage. Water leakage into the system dilutes the product and increases the evaporation load, thereby increasing the energy consumption. For example, for a triple-effect evaporator, a leak averaging about 8 litres per minute per 10,000 kg evaporation can result in net increased steam consumption of 2%.

The water can enter the system from flush lines or condenser flooding or by the excessive rinsing of the system to prevent the building of scale or deposits in instrument lines, traps, or sight-glasses. Water leakage is one of the most severe problems affecting energy consumption which can be corrected by closer operator attention and maintenance.

Separator efficiency. The efficiency of the vapour separator depends mainly on the mass velocity entering the separator, and the liquid droplet size and viscosities. Decreased efficiency can promote entertainment of the product into the vapour line, which reduces not only the yield but may also cause coating of the vapour lines and vapour side of the tubes in the next effect. This would result in increase in losses in heat-transfer rate and pressure drops, causing increase in steam consumption. It is important, therefore, to maintain conditions which eliminate or minimize entrainment.

Proper maintenance and operation of spray dryers would generally include the following points to be considered:

- **Avoid leaks:** There should be no leaks on a new dryer installation, but in course of time seals on joints of pipe work etc. may become worn. They should be inspected regularly and replaced when any defect is located. Oven doors should be checked for signs of warping.

- Insulation which may have come off should be replaced. The heat loss from the spray dryer structure should be calculated periodically by performing heat balance. The heat loss may range, depending upon the insulation already provided, from 5 to 25%. If the heat loss is on the higher side, providing more insulation would probably be justified at today's fuel prices. As a rough guideline, any surface having a temperature about 50 ^{o}C should be considered.

- Burners should be kept clean and operated at the air-fuel ratio with optimum quantity of excess air required for complete combustion. Regular monitoring the CO_2 content of the exhaust gas is a useful check with direct-fired dryers.

3. HIGHER CONCENTRATION OF FEED

Milk is concentrated in an evaporator before it is fed into the spray dryer. As dryers are thermally less efficient than any other heat transfer equipment, it is more economic to remove moisture in, say, multiple effect evaporator than in a dryer. Therefore, the dryer feed should be concentrated in evaporators to as high degree as possible and suitable.

For instance, consider drying milk in spray dryer from 60% moisture to 3% moisture. To a rough approximation, the energy used in the dryer is directly proportional to the evaporative load. Now if the milk is concentrated in an evaporator to 50% moisture instead of 60%, the energy consumption in the dryer will be reduced by:

$$\frac{(60-50)}{(60-3)} \times 100 = 17.5\%$$

This, however, is not the net saving. If a four effect evaporator, for instance, is used to concentrate milk to 60% moisture, roughly 150 kcal of energy is required (taken on higher scale) for each kg. of water evaporated, whereas in conventional spray dryer roughly 1200 kcal energy will be required for one kg of moisture removal. That is about 80% saving. Thus the net saving of energy will be roughly close to 14%, which is quite substantial.

There is of course a maximum limit of concentration to which the feed can be concentrated, as too high concentrated milk is difficult to atomize in a spray dryer. Preheating the feed may permit for higher concentration as viscosity decreases as the temperature of feed increases.

4. HEAT RECOVERY FROM EXHAUST AIR

The poor thermal efficiency of spray dryer is largely due to the large amount of energy in the exhaust air: only about 50% of the energy supplied is used. It is estimated that about Rs.60 to 100 per 100 kg powder is lost in the form of heat in the exhaust air.

Recovery of useful heat from this large volume of air economically would greatly reduce the fuel consumption. The problem is not simple one though: the moisture and the entrained powder particles cause fouling of heat transfer surfaces reducing the overall heat transfer co-efficients. With careful selection and design of heat recovery unit and the system, however, heat recovery can be made to the extent of 20-25% and more of the total energy required. The heat contained in the exhaust air could be most conveniently utilized to preheat the incoming fresh air to the spray dryer (Fig. 1). This would require to employ a heat recovery system consisting of an air-to-air or air-to-liquid-to-air heat exchanger.

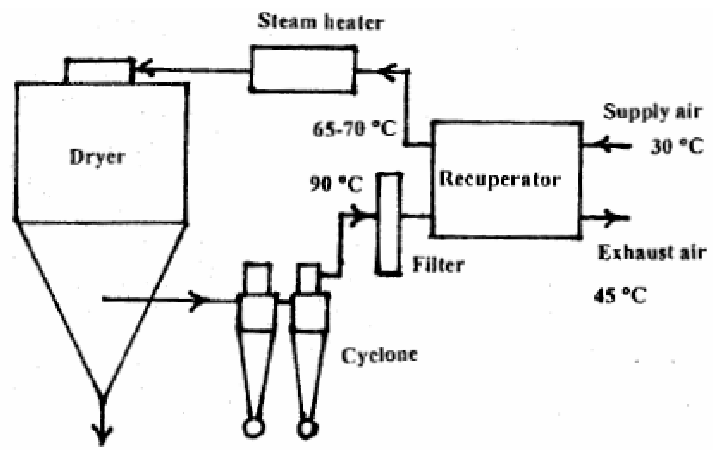

Fig. 1: Heat recovery in spray drying plant

Both systems are incorporated after the fines separator. Incorporating a bag filter prior to the heat recuperator increases the efficiency as the deposits on the heat transfer surface would be less. It is possible to operate the recuperator several days without cleaning, but if it proves necessary to clean the equipment, it can be done by means of a built-in clean-in-place (CIP) system.

The temperature of the dryer exhaust air normally ranges from 85 to 95^{o}C depending on the powder moisture content. Usually, the dew point temperature of this air is around 45^{o}C. Thus this air can be cooled to 45^{o}C, without condensing the moisture contained in it, by fresh incoming air thereby preheating it by around 40 to 50^{o}C. Systems can be designed wherein the exhaust air can be cooled further down to 40^{o}C or lower, thereby also recovering heat of condensation of condensed vapour from the air.

For a typical example of a single-stage spray dryer with fresh air temperature of 30 ^{o}C, drying air temperature of 200 ^{o}C, exhaust air temperature of 90^{o}C and cooling it to 45^{o}C (without moisture condensation) by fresh incoming air in a heat recuperator, the heat saved would be

$$\frac{(90-45) \times 100}{(200-30)} = 26.5\% \text{ of the total hat required.}$$

The air-to-air heat recuperator could be plate type of heat exchanger, heat pipes or thermal wheels.

Plate type heat exchanger: These heat exchangers comprise an open ended box filled with metallic, aluminum or stainless steel plates matrix which is formed into a multiplicity of narrow linear passages where rows of these transporting exhaust air alternate with those carrying fresh air (Fig. 2). Heat energy is transferred through the plate walls from the hot air to the fresh air. If the air is cooled below its dew point, condensation will occur and the condensate formed escapes via a drain in the bottom of the casing.

This system has high efficiency, no moving parts, ability to cope with dust laden air as this type can be easily inspected and cleaned. Payback period of less than one year has also been reported.

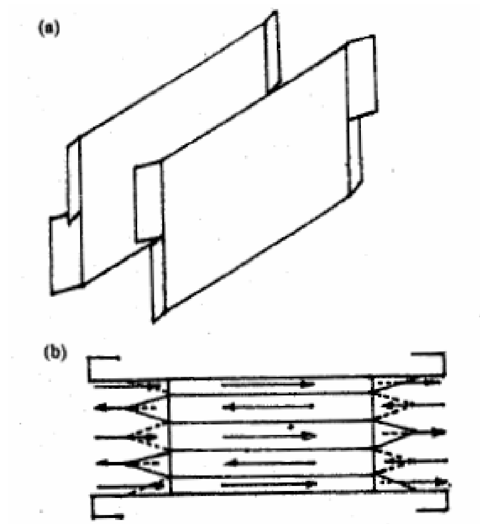

Fig. 2: Recuperator plates and air flow

Heat pipes: Heat pipes are closed evaporation condensation systems capable of transferring thermal energy at a high rate. A refrigerant / working liquid and a capillary wick are permanently sealed inside a metal tube. Heat energy applied to either end of the pipe causes the refrigerant to vaporize. This vapour then travels to the other end of the pipe where the thermal energy is removed by a cold stream. The vapour condenses back to the liquid, then flows back to the opposite end through the capillary wick as shown in Fig. 3. Thus, a continuous evaporation-condensation cycle is set up provided there is a heat source along one end of the pipe and a heat sink along the other end.

In a heat pipe heat exchanger a number of heat pipes are set horizontally in a frame, with each pipe extending across the total width of the unit, which is vertically separated into two ducts. Thermal energy is transferred horizontally through the pipes from the warm air in one duct to the counter flowing cool air in the other duct. The pipe itself may be made of aluminum, copper or stainless steel, with diameter of 1 to 2.5 cm and length upto 6 meters. The refrigerant may be Freon, water or diphenyl based fluid, depending upon the operating temperatures. Heat pipe heat exchangers are suitable for exhaust air temperatures upto 315°C and have heat recovery efficiencies over 85%. An air velocity of 2 to 4 m/sec is usually used on both the sides. However, as the hot air from the spray dryer will contain some milk powder, a system of this kind would be prone to fouling, requiring regular shut down for cleaning. Properly designed system may have payback period as low as 6 months.

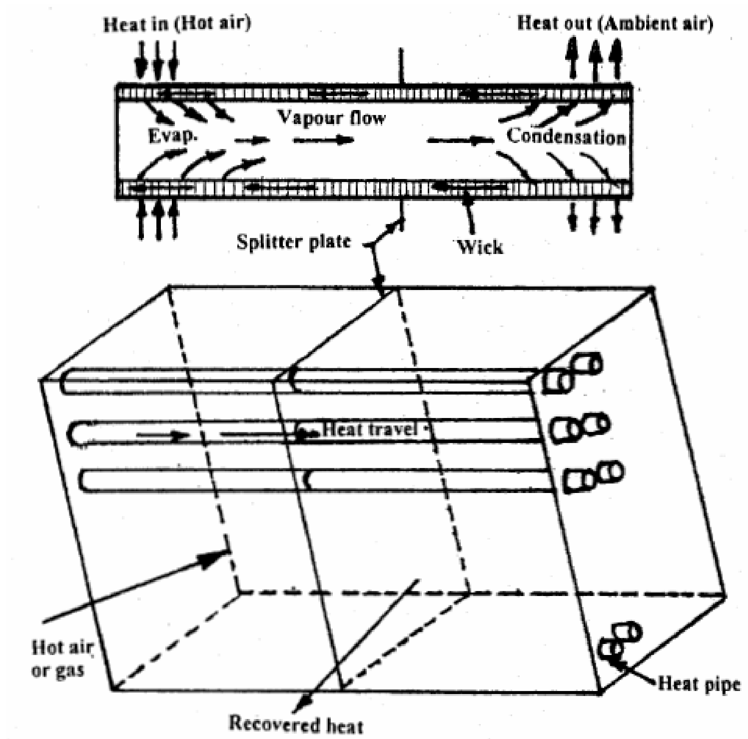

Fig. 3: Heat pipe heat exchanger

Rotating thermal wheels: Rotating wheel heat exchanger consists of a wheel (disc or drum) in an enclosure with separate ducts for exhaust and fresh air streams, as shown in (Fig. 4). The wheel revolves slowly, upto 10 rpm. The exhaust and the fresh air streams flow counter-current to each other. The hot air gives up its sensible heat to the wheel which transfers it to the cooler air stream during a later phase in its revolution.

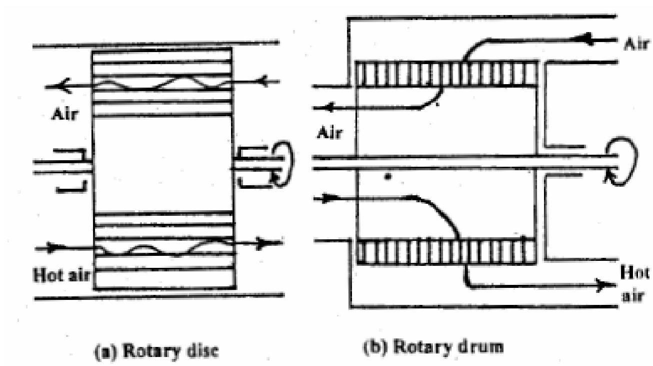

Fig. 4: Thermal wheel heat exchanger

The wheel is made of knitted wire mesh, metal, ceramics or plastics. Thermal efficiencies as high as 80% for equal mass flow rates have been claimed.

This system, however, allows contamination of the fresh air by the exhaust air, in the order of 2-4% of the main air flow. This can be reduced by equipping the heat exchanger with a purging section.

Air-liquid-air indirect contact heat exchanger: Air-liquid-air system consists of two heat exchangers, one in the exhaust duct and the other in the fresh air duct, connected by a pipe loop, as shown in (Fig. 5). Liquid, usually water with or without an antifreeze additive such as glycol, is pumped around the loop.

The exhaust air at 85-90^{o}C passes through the tubes of the heat exchanger where it delivers sensible heat to the liquid and cools down to about 40-45^{o}C. The liquid in turn preheats the supply air.

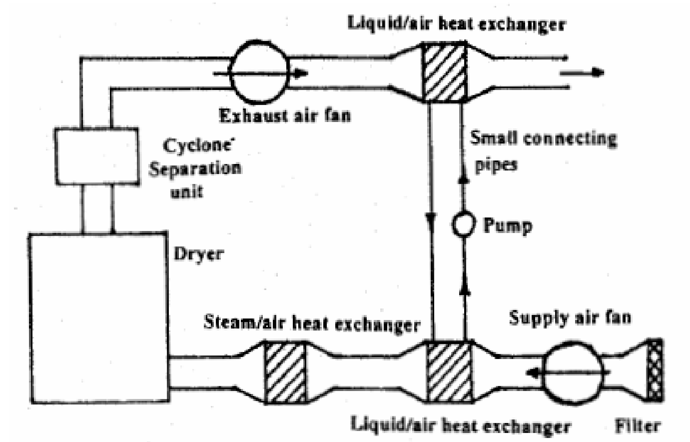

Fig. 5: Waste heat recovery by air-liquid-air heat exchanger

The heat exchangers are required to be cleaned at regular intervals due to fouling by milk powder in the exhaust air.

Heat pump: Heat from the exhaust gas may also be recovered by using a heat pump or dehumidifier. The exhaust gas or air is passed over the evaporator coil of the heat pump. After dehumidification the exhaust air passes over the condenser coil where the heat extracted in the evaporator coil is given back to it (Fig. 6).

There is no heat loss from the exhaust air. The dehumidified, reheated air is then finally heated in air heater to desired temperature and returned to the dryer. The energy required in compressing the working fluid in the heat pump is electrical energy. As a rough estimate about 1 kw of electrical energy will transfer 3 kw of heat and thereby achieve 3 kw of drying.

Although electricity is more costly than primary fuel energy, the system may prove attractive considering that the primary fuel utilization efficiency will be roughly 50%. Thus by expending 1 kw of electrical energy we save 6 kw worth of primary fuel. In using surface heat exchangers to recover heat from the exhaust air, fouling usually presents cleaning problems. It is, therefore, recommended to filter the exhaust air from about 100-160 mg/m^3 air concentration to less than 20 mg powder / m^3 of air. Such filtration, however, is not required when using wet scrubbers.

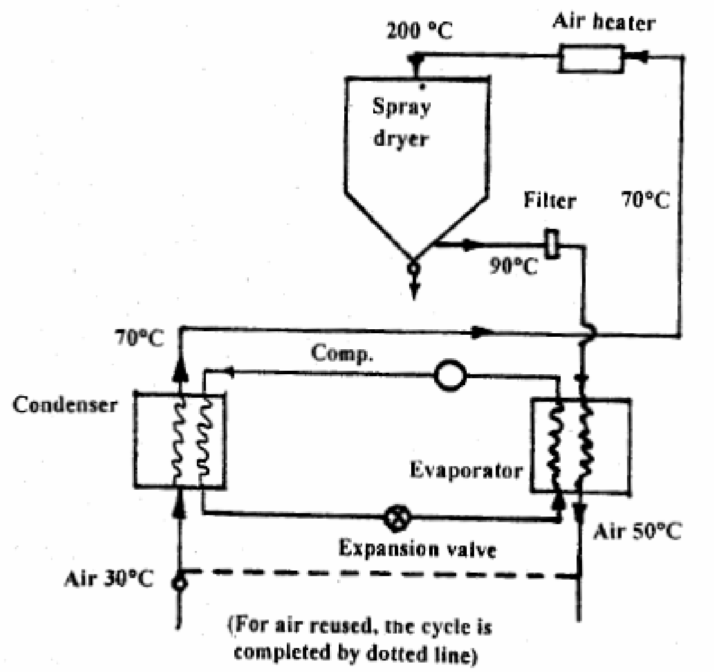

Fig. 6: Spray dryer with heat pump

Wet scrubbers: This is another method of heat recovery from the dryer exhaust air.

In wet scrubbers, the exhaust air flows through a milk spray in a spray chamber, a cyclone or through a venturi, into which milk is injected at the throat section (Fig. 7). The heat in the exhaust air will preconcentrate and partially preheat milk. Additionally, the powder entrained in the air would dissolve in the milk, thereby reducing product loss.

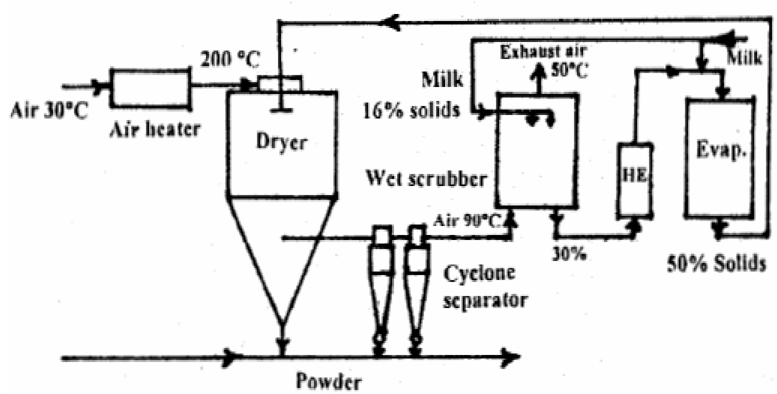

Fig. 7: Heat recovery in spray dryer employing wet scrubber

In this system the air temperature can be effectively brought down to about 45°C. Fig. 7 illustrates such a system. The temperature in the scrubber offers favourable conditions for bacterial contamination. The scrubber should therefore be used only when milk of first class is available. If the equipment is operated according to the instruction manual, which describes intermediate cleaning after 10 hours, the bacteriological activity will be minimum, as the retention time is considerably less than the generation time of bacteria. Part of the advantage is however lost due to the intermediate cleaning.

5. TWO-STAGE DRYING

In conventional spray dryer the milk is dried to 3 or 4% moisture in a single stage. The energy required per kg of water removal is roughly 1200 kcal. It is well known that the final stage of drying requires large proportion of energy for removing moisture from the product, because the moisture transfer from within the droplets to surface is governed by internal diffusion of water within the droplets which is slow. In the final stages of drying the moisture concentration is less, and consequently the diffusion is less. Further, resistance to moisture transfer increase as the surface dries. If relatively long residence time is permitted to remove the moisture, the drying will be more economical.

Thus, if in the spray dryer the moisture is removed to a level, which is safe from caking and adhering to the dryer walls, say about 6-7%, the remaining amount of moisture, from 6% to 3% may be removed in a fluidized bed dryer, which uses smaller quantities of air and at a lower temperature. The residence time in this dryer can be quite long, approximating of the order of one-minute compare with a few seconds in a spray dryer. Advantages of such a two stage dryer, compared with the conventional single stage plants, are many including 15-20% saving in heating energy.

6. OTHER MEANS OF SAVING ENERGY

There are other ways of saving energy in powder plants. While designing the factory, the air inlet filters can be located inside the building where the dryer is. The inlet air temperature would then be higher, decreasing the heat requirement. However, the air near the dryer may pick up moisture decreasing the air's drying capacity. Besides, the cold air rushing inside may cool some parts undesirably, for example cyclones, causing the risk of condensation and deposits. Hence, these should be considered duly.

Another way of conserving energy is to preheat drying air with the condensate from second effects further on. The condensate from the first effect would be returned to the boiler as feed water. The condensate from other effects would be at an average temperature of about 55-56^{o}C, which can be cooled to around 35^{o}C.

Similarly, the last effect vapour (temperature 45-50^{o}C) can be condensed by the incoming drying air, thereby preheating it. However, the drying air may not be able to condense all the vapour, and therefore, an additional condenser may be necessary, with adequate flexibility to account for the increase in ambient temperature. Alternatively, the vapour may be condensed by incoming feed, thereby preheating it. This would recover the heat of condensing from the vapour and would decrease the requirement of condensing water, if not eliminate it altogether.

The condensate produced in the steam heater for heating drying air, can be used to produce flash steam and then the flash steam can be used to preheat the drying air (Fig. 8).

If indirect oil or gas fired air heaters are used, it is possible to install a process air / combustion air heat rcuperator directly on the air heater. The combustion gas has typically a temperature of more than 300^{o}C, but the quantity is low. Such a system needs to be examined and designed carefully.

Another way of saving energy is to start up the equipment in the right sequence, i.e., to ensure that the spray dryer is started so late that it will not be 'waiting' for concentrate, as a considerable amount of energy is wasted during such a waiting time. Computerized instrumentation including automatic start-up is a solution to overcome such a problem.

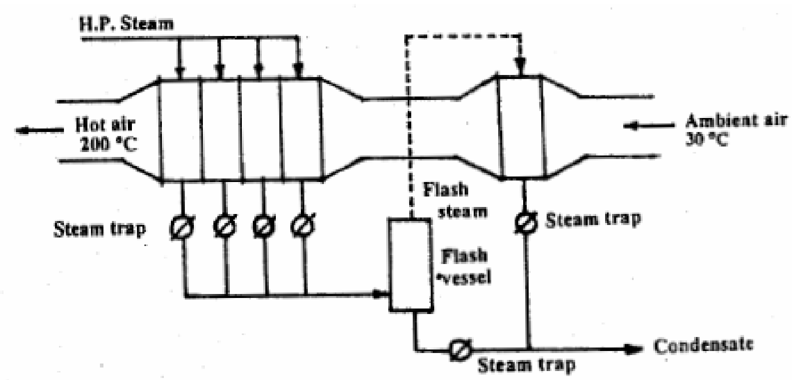

Fig. 8: Flash steam recovery in air preheater

7. SUMMARY

The above details show that tremendous savings can be made in energy expenditure by employing appropriate technology and energy saving methods. Two-stage drying and heat recovery may reduce the energy requirement to about one third in many cases. The existing plants should be examined for energy economization possibilities, appropriate proposals developed and the same should be implemented. The measures could be just common-sense application, minor technical modifications requiring small investment or major upgradation needing comparatively large investment. Depending upon the feasibility, these measures should be applied. The benefits realized would be substantial – the payback period may be a few months or upto two years. The plant can then be highly competitive product cost-wise.

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Quality and Plant Management Group
National Dairy Development Board
PB No.40
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Fax No. (02692) 260157